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Reference

An In Situ Multilevel Sampler for Preventive Monitoring and Study of Hydrochemical Profiles in Aquifers

by Daniel Ronen, Mordeckai Magaritz and Itzhak Levy

Abstract

A modular multilevel sampler was developed and utilized for sampling undisturbed ground water chemical profiles and gases in both the saturated and the unsaturated zone. Sampling at 3cm depth intervals is based on the dialysis-cell method and has no depth limitations. The sampler may be used for the development of early warning monitoring systems and research.

Introduction

The increasing need to understand the processes of ground water contamination has necessitated the development of new ground water sampling techniques. A major problem in hydrochemical studies lies in obtaining representative ground water samples from discrete zones. Generally, samples are collected from production wells or by samplers lowered to different depths in observation wells. These procedures disturb chemical gradients and can yield mixed water samples from different horizons of the aquifer. Devices used to obtain profile samples that have been reported in literature have been used primarily for shallow aquifers. In most of these devices, the water sample is pumped from the surface and the sampling intervals are greater than 0.5m (Hansen and Harris 1974; Oberman 1976, 1982; Edworthy and Brown 1976; Pickens et al. 1978; Harrison and Osterkamp 1981; Molz et al. 1986).

Some samplers developed for pore water studies in lakes have employed the dialysis membrane technique. This consists of placing a sampler with dialysis cells filled with distilled water at the sampling site and leaving it there so that the ambient water and the cell water can equilibrate (Mayer 1976, Hesslein 1976). Sampling intervals of 1cm have been achieved using this method.

The equilibration time of a dialysis cell system can be calculated using Fick's second law of diffusion, given by Crank (1975) as $C=(Co/2)\mathrm{erfc}[x/2(Dt)^{1/2}]$ where C=concentration, Co=original concentration, D=ionic diffusion coefficient for a specific temperature.

In the framework of a study of the processes taking place in the region of the water table the authors developed a multilevel sampler (MLS) based on the dialysis cell technique. The sampling interval (of the existing instrument) is 3cm and it can be utilized in either shallow or deep aquifers.

Sampler Construction

The sampler (Figure 1) consists of a 5cm diameter PVC rod 135cm long with 38 perpendicular crisscrossed holes (A) to accommodate the dialysis cells (B). The cells are spaced at 3cm intervals and separated by flexible

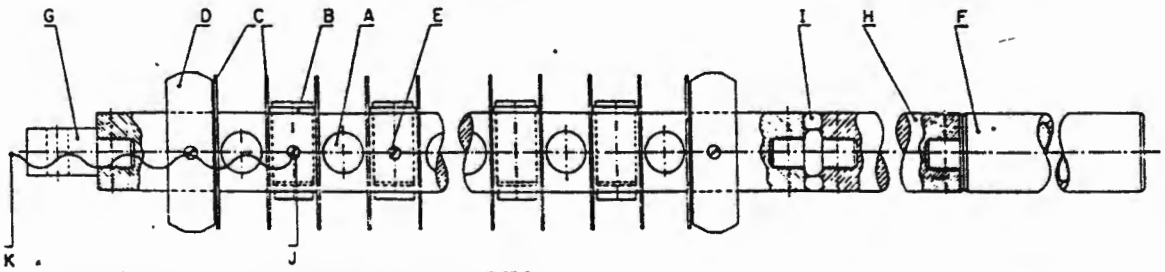

Figure 1. Schematic representation of the multilevel sampler (MLS).

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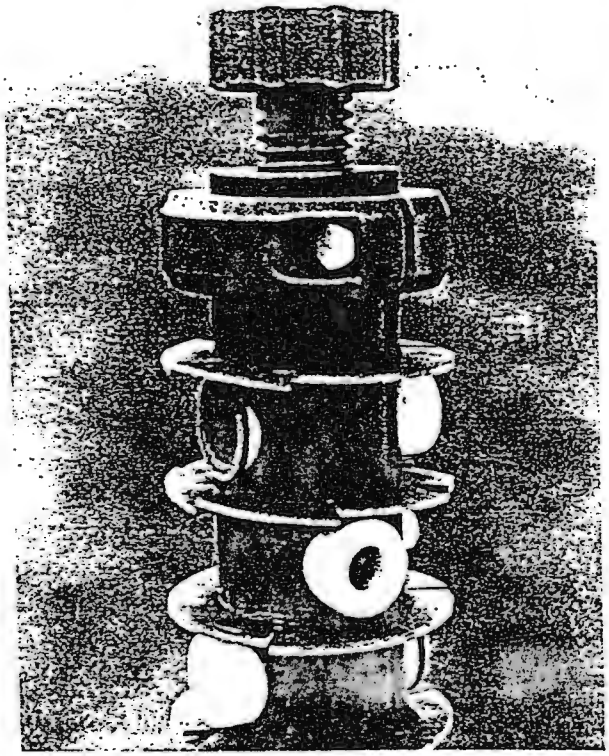

Figure 2. Segment of the MLS showing the dialysis cells, flexible rubber seals and PVC ring.

rubber seals (C) that fit loosely in the inner diameter of the sampling well. Two PVC rings (D), the purpose of which is to guide the sampler through the well, are mounted at both ends of the rod (Figure 2). The dialysis cells are secured by nylon screws (Figure 1,E); one of them, a stainless steel screw (J) is connected to the surface by an insulated stainless steel wire (K). A PVC-coated weight (F) is connected to the lower end of the sampler. A nylon rope is attached to the upper holding segment (G). The sampler is built in modules so that several rod segments (H) may be connected by a double-screw (I). Figure 3 shows a sampler composed of two rod segments and two weights. The dialysis cells (B), are built of modified polyethylene vials with replaceable dialysis membranes on both ends (Figure 4).

In order to empirically determine the equilibration time in the system, a laboratory test was performed in which five pairs of dialysis cells were submerged in separated baths of an 800 ml solution (Cl^- = 200mg l^{-1}; NO_3^- = 100 mg l^{-1}; $SO_4^=$ = 60 mg l^{-1}) that were mixed once each sampling day.

The performance of the sampler was tested measuring an electrical conductivity profile in a bath in the laboratory. A salinity gradient was artificially built in a container filled with tap water by introducing a cold saline solution (1 gr NaCl in 1 kg H_2O) in the bottom. Two consecutive profiles were sampled after an equilibration period of seven days.

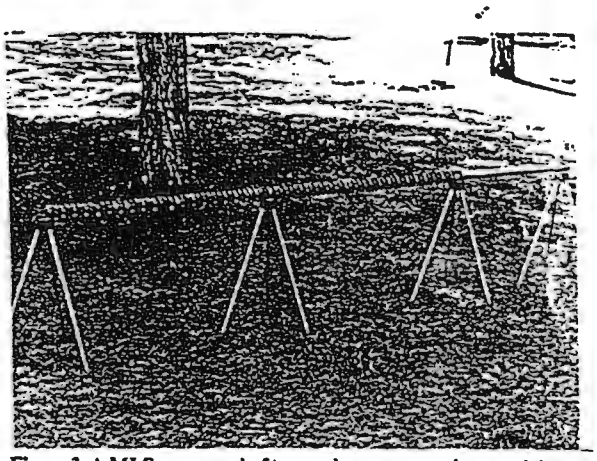

Figure 3. A MLS composed of two rod segments and two weights on tripods, which can be disassembled.

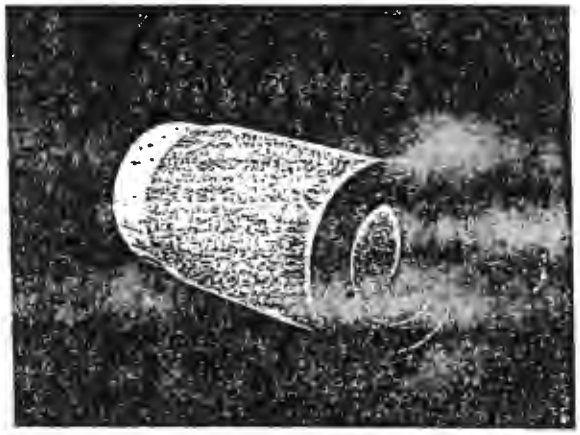

Figure 4. A 20 ml dialysis cell with Union Carbide C-75 (40 Å) dialysis membrane.

Research Well

The sampler must be utilized in a screened well. As the aim of this study was to develop a system to monitor the arrival of pollutants to the water table, the authors designed and drilled research wells for this purpose (Figure 5). The wells are located in the deep, sandy and phreatic Coastal Plain Aquifer of Israel. The depth to the water table is about 27m and the thickness of the saturated zone is about 130m. The wells were drilled using a hollow-stem auger without the addition of water. PVC pipe was used as well casing. Bonded-on gravel-pack screens (Pumpen-Boese-KK Filter 80/0.6/0.7-1.2; Klotz 1979). were placed both 3m above, and 5m below the water table. The position of the screens in relation to the water table was selected using these parameters: both the monthly and yearly fluctuations of the water table, and the ability to sample the gas composition of the unsaturated zone above the water table.

A stainless steel wire mounted on one of the screens was connected to the surface by a PVC-coated stainless steel wire.

Water Sampling

The dialysis cells, filled with distilled water, were inserted into the sampler. The sampler, composed of two connected segments of MLS, with a total sampling length of 241cm, was lowered into the research well; it was kept

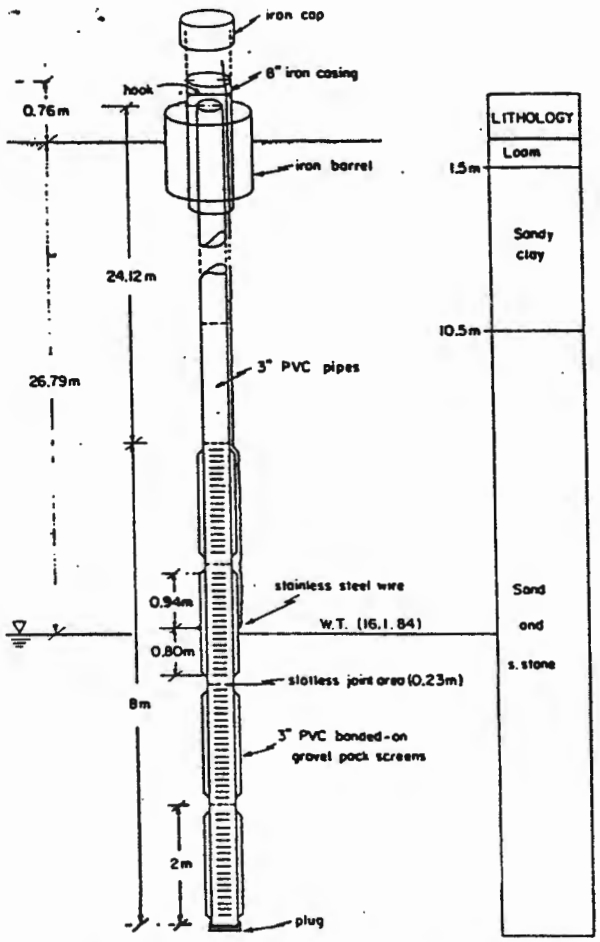

Figure 5. Schematic representation of research well WT-2 and lithological profile.

in position by attaching the nylon rope to the well hook. The exact position of the water table in relation to the dialysis cells was determined by connecting both stainless steel insulated wires (the wire mounted on one of the screens [Figure 5] and the wire connected to the sampler [K in Figure 1]) to an ohmmeter. The sampler was left for an equilibration period of 30 days.

Water samples were analyzed for Cl^-, NO_3^-, $SO_4^=$ and conductivity. The anions were measured by a Wescan model 261 ion analyzer system with a precision of ±4 percent; conductivity was measured by a CDM-1 conductometer.

Results and Discussion

The equilibration times of the dialysis cells and the laboratory and field performance of MLS are presented in Figures 6, 7 and 8. Excellent sampling reproducibility was obtained from different dialysis cells located in the same solutions for different equilibration times (Figure 6 and Figure 7). The sampler was also capable of allowing the measurement of both large (Figure 7) and small (Figure 8) salinity gradients at 3cm intervals. The natural chemical profile presented in Figure 8 is constructed from 55 individual samples collected at minimum intervals of 3cm. Note the sharp gradients detected in the concentrations of NO_3^- (55 to 155 mgL^{-1} in the top 15cm

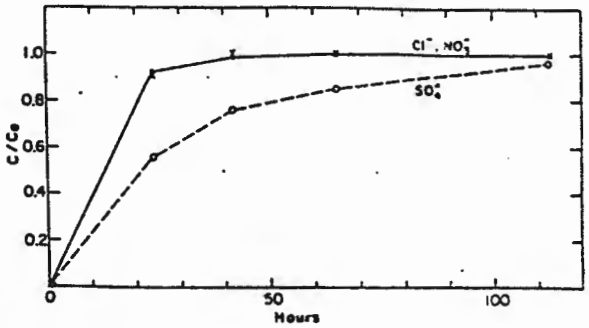

Figure 6. Equilibration test of dialysis cells conducted at 22 C. o-Cl^-, x-NO_3^-, o-$SO_4^=$; each point represents two equilibration tests. The dialysis membrane used was Union Carbide C-75.

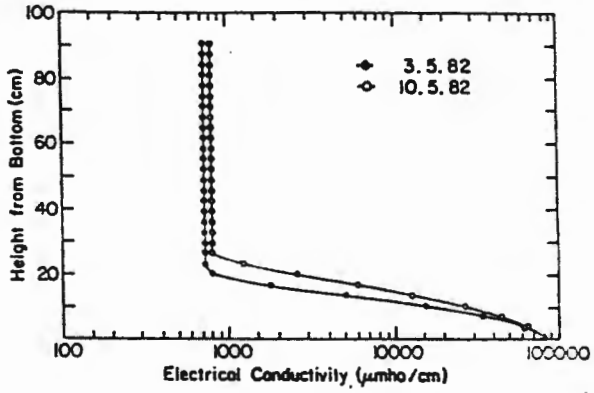

Figure 7. Electrical conductivity profiles measured in a water tank by the MLS.

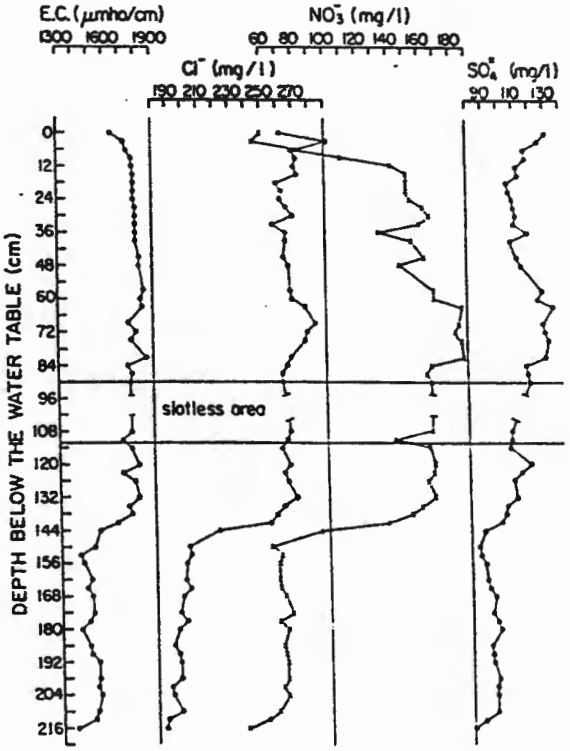

Figure 8. Field profile of conductivity, Cl^-, NO_3^- and $SO_4^=$ as measured by the MLS in research well WT-2 (20.9.84).

of the saturated zone and 170 to 65 mgL^{-1} in the 130 to 150cm interval) and Cl^- (255 to 200 mgL^{-1} in the 130 to 150cm interval). Such chemical profiles cannot be detected by commonly used technologies. Sampling of these profiles in the field was possible because the flexible seals separated the filter tube into different sampling segments, preventing mixing by vertical currents or diffusion. The dialysis cells in each segment allowed undisturbed samples of the flowing system. No chemical profile was detected in this well when it was pumped from different depths at very small rates (200 liters per hour) by a pneumatically operated pump or when the sampler was lowered into the well without the flexible seals.

The equilibration test (Figure 6) shows that for Cl^- and NO_3^-, 90 percent equilibration is obtained within 24 hours whereas only 50 percent equilibration is achieved for $SO_4^=$, as expected because of its lower diffusion coefficient. Clearly, total equilibration for these anions is obtained within one week. In this study, a 30-day sampling period was chosen to allow re-equilibration of the well-aquifer system to "normal" hydrochemical conditions after lowering the sampler into the well. Shorter sampling periods may be chosen according to monitoring needs. The minimal sampling time is defined by the equilibration time of the chemical species and the desired equilibration percentage.

Dialysis cells of Pyrex with Teflon® O-rings were constructed (Figure 9) to test the suitability of the system for sampling organic micropollutants. Preliminary laboratory results are presented in Figure 10. The MLS was also used to study the distribution of gases (O_2 and N_2O) dissolved in ground water and in the unsaturated zone just above the water table (Ronen et al. 1987, Krajenbrink et al. 1987, Almon 1987). It was found that biodegradable organic matter (measured as dissolved organic carbon) reaches the water table after long transport periods (about 15 years) through the unsaturated zone. The oxidation of this organic matter depletes the dissolved oxygen content of the water table region (Ronen et al. 1987).

A modification of the point dilution technique, using ^{18}O depleted water as a tracer, and the MLS was used to obtain detailed profiles of the horizontal component of the specific discharge (Ronen et al. 1986) in the water table region. The study of hydrochemical processes including denitrification, carbonate mineral dissolution and precipitation, and destruction of organic moieties, that take place at the water table region may greatly increase our understanding of ground water pollution processes.

The potential of this methodology should be recognized for the development of "early warning" ground water monitoring systems (Ronen et al. 1985). Sampling and measuring the actual contaminant fluxes reaching the water table from the unsaturated zone, before they are diluted in ground water, has several advantages: (1) it increases the detection sensitivity of the monitoring system, as pollutants arriving from the unsaturated zone will be found at maximum concentration in the water table region (Ronen and Magaritz 1985); (2) it gives ample time (decades) for remedial actions to be under-

Figure 9. Dialysis cell of Pyrex with Teflon® O-rings and Versapor-200 dialysis membrane.

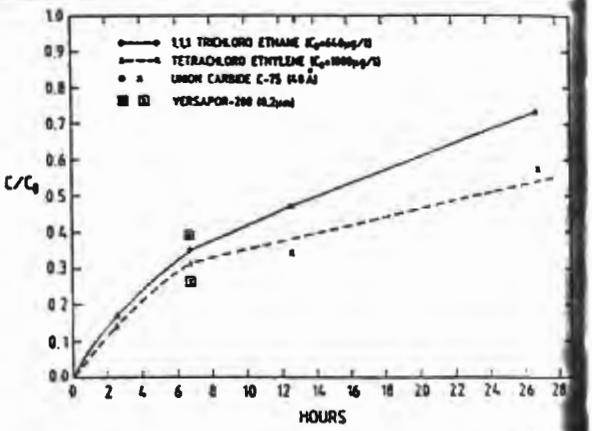

Figure 10. Preliminary results of equilibration test with Pyrex dialysis cells and two different types of dialysis membranes. The dialysis cells were submerged in separated baths and continuously stirred at 22 C (the experiment was stopped after 28 hours for technical reasons).

taken before massive ground water contamination occurs and (3) it enables establishment of a quantitative relationship between the amount of pollutant released in the soil and the amount that actually reaches ground water. The MLS is portable (Figure 11), inexpensive and easy to operate. The dialysis cells are in continuous dynamic equilibrium with the gas and liquid phases in the aquifer. Therefore, the MLS is a continuous sampling system. It may be lowered in any existing screened well and its sampling depth is not limited. Its dimensions are a function of the well diameter. The sampling volume is mainly defined by the desired sampling intervals. The system used by the authors (sampler and research well) was specially built of PVC to permit the future study of heavy metals in the saturated zone. However, the building materials of both the sampler and research well, as well as the type of the dialysis membrane, can be selected according to the monitoring and research needs. The MLS has been used continuously to study the water table region in Israel (from 1984 to 1987) in an agricultural area irrigated with sewage effluents and in the Netherlands (1986) in a forest region subjected to the input of acid rain (Krajenbrink et al. 1987).

A patent application has been filed by the Israel Water Commission and YEDA Research and Develo

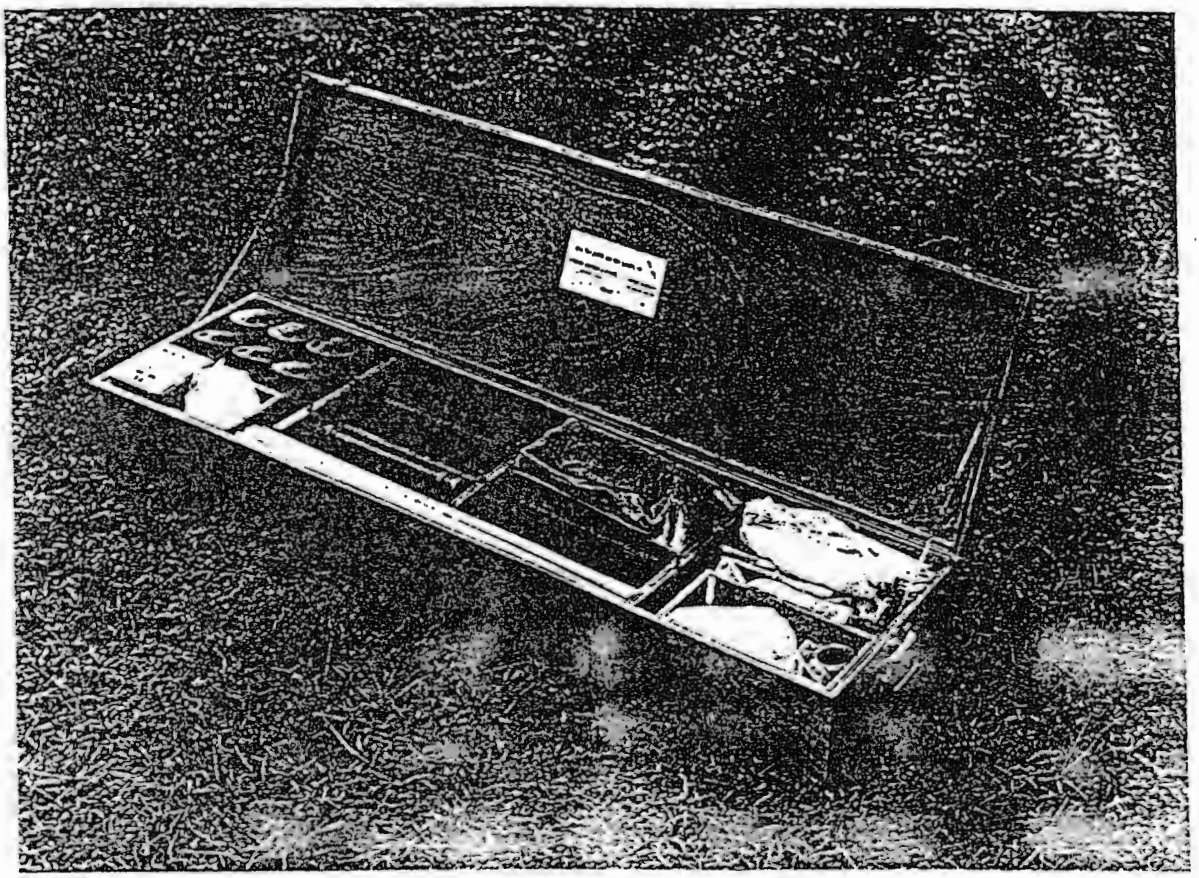

Figure 11. Disassembled multilevel sampler in carrying case.

ment Co. Ltd., for the monitoring system described in this paper.

Acknowledgments

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Biographical Sketches

Daniel Ronen works at the Isotope Department, the Weizmann Institute of Science (76100 Rehovot, Israel) and the Research Department of the Israel Hydrological Service. He specializes in the development of ground water and surface water monitoring systems and on the study of transport and chemical processes in the water table region.

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Itzhak Levy is a design engineer in the Departmen of Instrument Design, the Weismann Institute c Science.

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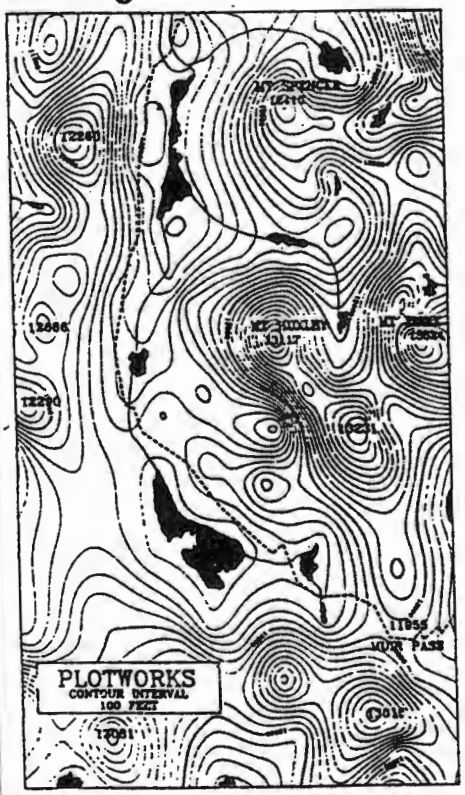

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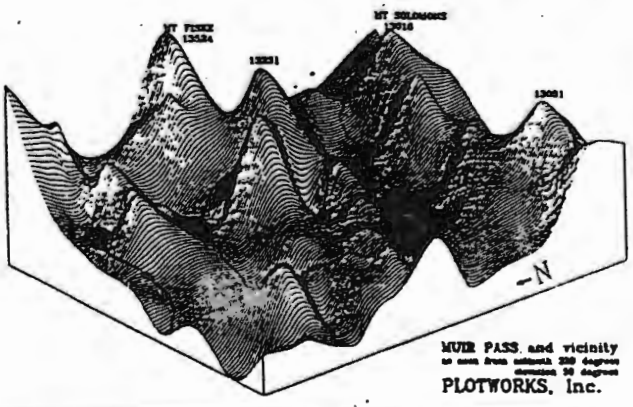

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